

ATTACHMENT 4

Exhibit 10-C, Attachment 10 of the March 2012 Temporary APP Application

TECHNICAL MEMORANDUM



To: Daniel Johnson- Curis Resources Ltd.

Title: Geochemical Evaluation of Forecast Process Solutions at Florence Copper Project for Pilot Testing of In-situ Copper Recovery

1875 LAWRENCE STREET, SUITE 500
DENVER, COLORADO 80202, USA

Project No.: 020368

From: Drummond Earley

Date: February 22, 2012

Pages: 14

TELEPHONE: (303) 297 9005
TELEFAX: (303) 297 9007



1 BACKGROUND

Curis Resources (Arizona) Inc. is currently applying for a temporary APP for its production test facility (PTF) for an In-Situ Copper Recovery (ISCR) process that involves the dissolution of copper from a geologic ore body by circulating a leach solution (sometimes referred to the "lixiviant", Larson, et al., 1988) through a largely intact and unmoved rock mass and to recover the solution for processing of their metal values. This recovery method requires a detailed understanding of coupled groundwater flow and geochemical reactions in the subsurface (Bartlett, 1992). A description of the hydromechanical/thermochemical processes that may be involved in ISCR systems is summarized in Tsang (1991). An aqueous (water based) sulfuric acid solution (usually between 10 to 100 grams per liter H_2SO_4 depending upon the acid consumption characteristics of the host rock) is the most common lixiviant of choice for ISCR operations. Sulfuric acid is readily available in the form of H_2SO_4 produced from smelter by-products. The ISCR process that will be used at the PTF uses injection and recovery wells exclusively to circulate the lixiviant and recover metal-laden solutions in an otherwise undisturbed ore body.

Because no excavation of the rock mass is involved, injection and recovery capacity is largely dictated by the naturally connected pore spaces in the igneous host rock in the form of fractures that have developed from natural geologic processes. Therefore, the minerals that are dissolved are those that are commonly associated with the fractures, like copper oxide minerals, whereas other minerals may remain unleached in the rock matrix owing to low solubility or poor solution mineral contact. Due to this complex distribution of minerals in the rock matrix, empirical leaching tests are required to integrate all the water rock interactions for estimation of the composition of the leach solution as the mineralogy and texture for each deposit is unique.

The advantages of ISCR over conventional mining include reduced surface disturbance, and energy expenditures. In addition, ISCR also circumvents groundwater dewatering and lowering of the regional water tables. These operational efficiencies allow for copper production from deposits that would otherwise be too deep and too low-grade for conventional excavation-based mining.

This Technical Memorandum provides a summary of the geochemical analysis, including computer modeling that was conducted in support of a temporary APP application for the PTF. The copper ore deposit in the vicinity of the PTF was tested for ISCR feasibility in 1997 and 1998 by BHP Copper Inc. (BHP). The project is located approximately four kilometers

northwest of the City of Florence's commercial district within the incorporated agricultural lands of Pinal County, Arizona. The ISCR target is the oxidized portion of a porphyry copper deposit and is hosted by a fractured Precambrian quartz monzonite and Early Tertiary granodiorite porphyry that is overlain by 120 meters of unconsolidated basin fill (Seguin, 1997). The primary ore mineral in the oxide zone is chrysocolla and its occurrence is more or less evenly distributed between fractures and the rock matrix as determined from geostatistical evaluation of geologic data by Schlumberger Water Services (SWS) using Petrel software. Minor amounts of copper-bearing goethite and Cu-Fe-Mn oxides (copper wad) are also present in the oxide ore. Associated fracture-controlled minerals include smectites, kaolinite, hematite, goethite, and calcite. There is a relatively abrupt transition from the oxide zone downward into the sulfide zone where chalcopyrite and pyrite mineralization is present.

The potential reactions and byproducts of the lixiviant dissolution of ore were originally investigated by BHP using a combination of laboratory and field testing and geochemical modeling. These investigations are summarized in the original APP Application (for APP No. 10174), Volume IV, Modeling Report prepared by Brown and Caldwell (1996). In addition to the laboratory and field test work, the geochemical processes associated with the proposed ISCR were explored using numerical modeling and experimental laboratory column tests. These numerical simulations and experimental tests were designed to extend the data sets generated by laboratory and field testing to evaluate the leaching of copper and other constituents during full-scale ISCR operations, metal attenuation, acid neutralization, and dilution (washing) processes. Updated geochemical modeling, using proven geochemical modeling software, has been conducted by Curis Arizona for this temporary APP application. The modeling was performed to develop updated forecasts of the composition of process fluids and that will be produced during ISCR at the PTF. The modeling objectives, scope, methods, simulation results, and conclusions are summarized in Sections 1.1 through 4 below. Cited references are provided in Section 5.

1.1 Purpose and objectives of the geochemical modeling investigation

The primary purpose of the geochemical evaluations being conducted for the temporary APP application is to use site-specific geologic, hydrologic, and geochemical data in numerical computer modeling simulations of ISCR at the PTF to estimate the composition of process fluids and streams, and the potential impacts on surrounding groundwater quality. In addition, geochemical modeling is being used to evaluate water management and treatment options during ISCR. The computer simulation results are presented herewith in support of Curis Arizona's Temporary APP application.

The primary objectives of the geochemical model simulations developed for the PTF include:

- Estimate the concentration of constituents in the ISCR process and solutions as identified in the existing APP 101704.
- Predict the potential impacts on groundwater quality after the cessation of operations.

This technical memorandum summarizes the development of the geochemical models and simulation results with respect to constituent compositions and distributions in these media.

1.2 Scope of geochemical modeling

The scope of the geochemical modeling included integration of the combined results of laboratory column testing, field leach testing and mineralogical evaluations to simulate the process of fluid/rock interactions and fluid/fluid mixing to extend the predictive capabilities of the geochemical

analysis of the system to pilot and full scale ISCR operation. For example, a fully mature leach solution was not developed in the relatively short duration and extent of the laboratory and field trials. Over time, geochemical processes have a natural capacity to alter the chemical composition of a leach or other process solutions by the mechanisms of dilution, hydrodynamic dispersion, mineral precipitation and other reactions. A geochemical modeling approach was developed to support the design of the ISCR system that maximizes the recovery of the copper from the ore reserve while minimizing the migration of heavy metals and other constituents into surrounding groundwater.

The scope items of the geochemical modeling work entails:

- A comprehensive review of site geology, hydrometallurgical testing results, hydrologic testing and analysis, and groundwater and pilot test geochemical data.
- Development of a conceptual model of the ISCR processes.
- Geochemical simulations of water/rock reactions of process solutions with the host rock media and ambient groundwater.

The geology of the copper deposit underlying the PTF is known from over 788,800 feet of exploration drilling (over 810 borings), geophysical investigations, and limited underground workings development. The copper oxide ore deposit is covered by over 120 meters of basin fill and leached cap material. Feasibility studies have shown that because of the deposit's grade (0.34% total copper of which 0.24% is acid soluble) and thick overburden depth, ISCR combined with Solvent Extraction-Electrowinning (SXEW) processing is the most economical method to extract the copper oxide reserves (BHP, 1997). Moreover, extensive geologic and hydrometallurgical evaluations have shown that the lithology, mineralogy, and structural settings are favorable to ISCR. The gangue mineralogy of the altered Precambrian and Tertiary intermediate host rock consumes acid at a relatively slow rate. In addition, a large proportion of the chrysocolla mineralization is associated with connected fractures providing pathways for leach solution flow and ore mineral contact (i.e. high sweep efficiency). In addition, material reactivity characteristics of the ore and country rock were determined from core leaching tests and attenuation studies in columns. A comprehensive ore database was provided to SWS by Curis Arizona and was rendered in Petrel for geostatistical analysis.

Characterization of the hydrological environment at the PTF is based on a conceptual hydrologic model and a field measurement program (Seguin, 1997, Brown and Caldwell, 1996). The unconsolidated basin fill rocks that overlie the copper deposit include Upper and Lower Basin fill units separated by an area wide fine-grained unit occurring about 60 feet above the bedrock surface at the top of the copper ore body. The water level occurs at a depth of approximately 150 feet beneath ground surface within the upper and lower basin fill units. A third aquifer occurs in the oxidized portion of the bedrock. The three aquifers have distinct compositional signatures. Further details of the hydrogeology and properties of the aquifer system are found in the Brown and Caldwell Modeling Report (1996) submitted as Volume IV of the BHP submittal of the original APP application.

In 1995 and 1996, BHP conducted hydrometallurgical and attenuation testing on core samples from the PTF ore body. Copper recovery, copper grade in solution, acid consumption, and metal attenuation capacity were measured in both the granodiorite porphyry and quartz monzonite host rocks. The results of these tests were summarized in Brown and Caldwell's Modeling Report (1996).

The conceptual geologic and hydrologic models developed for the PTF were integrated by SWS for the purposes of geochemical model development as described in Section 2 below.

2 MODEL DEVELOPMENT

To meet the goals and objectives of the geochemical modeling work the following approach was used in the development of the numerical model based on the conceptual geologic and hydrologic models and ISCR process:

- Analyze and reinterpret the site-specific geochemistry and understand the geochemical parameters and chemical transport parameters of the operational and post closure mine ISCR solutions using the Geochemists Workbench (GWB) software package.
- Conduct simulations of the ISCR operational components and closure/post closure groundwater conditions based on the current and more detailed understanding of the hydrogeology and geochemistry of the PTF.

The selection of the GWB geochemical computer code is based on SWS's knowledge of the proven geochemical models and the fact that GWB is widely accepted in the geochemical community for project planning applications in extractive industries and environmental permitting. Alpers and Nordstrom (1999) provide a more detailed treatise on geochemical modeling code capabilities and applications.

The geochemical reaction model was developed to forecast the composition of process fluids (including Pregnant Leach Solution [PLS], raffinate and water impoundment influent and water impoundment sediments) as generally proposed for the PTF ISCR operation. In addition, the geochemical model was developed for estimation of groundwater quality following rinsing and closure of ISCR operations.

The GWB model developed by SWS uses a modified form (the thermo.com.V8.R6+.dat) thermodynamic property database which is based on the Lawrence Livermore National Laboratory database, one of the most extensive and with the highest internal consistency of any geochemical thermodynamic databases in the public domain. This database also allows the simulation of elevated ionic strength solutions using the so-called B-dot ion activity model following the extended Debye-Huckel formulation in the geochemical simulations of aqueous speciation. The capabilities represented in GWB encompass the major processes occurring in the ISCR ore blocks. Namely, the following fluid/rock interaction processes were incorporated into the numerical geochemical model to simulate the acid leaching process and the natural capacity of the geologic units to limit or attenuate the migration of metals and other solutes:

- Mixing of different aqueous solutions
- Gas buffering, solid precipitation, dissolution and other equilibrium reactions
- Redox equilibrium and disequilibrium
- Activity models for aqueous speciation of high total dissolved solids concentrations
- Mineral dissolution kinetic rate laws

These are the most important geochemical processes that govern process solution composition and groundwater quality associated with ISCR.

2.1 Assumptions

The primary assumptions used in the GWB modeling are listed below:

- Standard state temperature at 25°C and standard state pressure (i.e., 1 bar of pressure).
- The distribution of copper oxide ore minerals in the ore body is homogeneous
- Constituent dissolution and release rates are constant with time.
- Oxygen partial pressures in process solutions fixed at 0.1 bar.
- Attenuation of constituents occurs through mineral precipitation, but no adsorption, desorption, or ion-exchange reactions are considered owing to low initial pH conditions and limited exchange capacity of the host rock as compared to the mass of constituents in the residual PLS.

The first step in the development of the geochemical model is to estimate the composition of the lixiviant or raffinate and PLS. The initial PLS and raffinate compositions were estimated using the GWB program module REACT to develop the model input file and to provide revised process water composition estimates.

2.2 Model configuration and numerical solution

The numerical model development primarily involves the construction of input files and scripts that translate the conceptual model into its mathematical representation, consisting of computer algorithms that provide the numerical solution of the governing partial differential equations. These equations are rendered as finite difference approximations in time. Adaptive time stepping and basis switching can be optimized by changing controls located in the input file and automatically in GWB codes to achieve convergence and stability, and to minimize runtime. The model adjusts the concentration of chloride in the initial water quality input data by charge balancing to maintain electrical neutrality.

The following data input were integrated in the model simulations:

- The distribution of copper in the bedrock surrounding the test ore block at the PTF is assumed to be homogeneous and at a copper grade of 0.2 percent by volume with the following ore and gangue mineral assemblage:
 - Chalcedony
 - Goethite
 - Chrysocolla
 - Illite
- A modified version of thermodynamic database thermo.com.v8.r6+ was used for all model calculations.
- For the purpose of the reaction path simulations, the mineral species listed below were suppressed from precipitating:
 - Cristobalite
 - $\text{Co}(\text{FeO}_2)_2$
 - Co_3O_4
 - Co_2SiO_4

- Cr_2O_3
- Goethite
- Hematite
- Magnetite
- Kaolinite
- Muscovite
- Ni_2SiO_4
- Phengite
- Quartz
- ZnCr_2O_4

Mineral and other phase suppressions are necessary because the GWB geochemical model is a "Path Finding Code". The selection of suppressed minerals was based on professional evaluation and the recommendations of Alpers et al. (1994) because they do not precipitate directly from solution at low temperatures owing to kinetic inhibitions.

3 MODEL RESULTS

The geochemical model results presented in this section include explanations of the computer simulations conducted to estimate ISCR process and solution component compositions as well as to estimate sediment composition and water quality in the water impoundments, and groundwater quality in the oxide zone following closure of commercial operations and after rinsing of the ore block is complete.

Eight distinct solutions and related components (Table 3.1) were estimated and updated for the purposes of the temporary APP application:

1. Composition of 93% H_2SO_4
2. Forecast Composition of Commercial Grade PLS
3. Forecast Composition of Raffinate
4. Estimated Composition of Pregnant Electrolyte (SX Strip Solution)
5. Forecast Composition of Water Impoundment Solution with 15 mg/L Lime Treatment
6. Forecast Composition of Water Impoundment Sediment After Evaporation
7. Forecast Composition of Groundwater Quality After Block Rinsing
8. Estimated Composition of Make-up Water

A description of each process solution and groundwater quality estimate and how its composition was derived is provided in sections 3.1 and 3.2 below, respectively.

3.1 ISCR process and solution component compositions -during operations

3.1.1 *Input Solutions Composition*

The estimated composition of process input solutions [1], [4], and [8] (listed above) were assumed to be the same as reported in BHP's original APP application in 1996 (Table 4.3-1; BHP, 1997). The compositions of these three solutions are dependent on selection, supply and availability of chemical reagents and make-up water resources. BHP's original estimates were based on other copper solution mining operations, and are likely to be of similar composition for the PTF regardless of the selection of water source, chemical reagents, and SX/EW operating conditions.

3.1.2 *PLS solution composition*

The compositions of PLS from copper solution recovery operations are characterized by high sulfate concentrations (thousands to tens of thousands mg/L) due to the sulfuric acid lixiviant in the injectate. In addition, magnesium, sodium, and aluminum concentrations usually build up in solution and reach several hundred to several thousand mg/L because these constituents are the most abundant in the igneous host rocks of the ore body and most soluble under the highly acidic lixiviant conditions. The levels of calcium (another major host rock element) in the PLS and raffinate solutions are usually controlled by saturation with respect to gypsum solubility, which in turn is affected by chloride levels (increasing chloride concentrations increase the solubility of gypsum at constant temperature). The concentrations of calcium are projected to range from 500 to 1000 mg/L depending upon chloride levels. The concentration of copper shown in solution 2 in Table 3.1 are managed by injection and recovery of leach solutions from selected ore intervals and wellfield sequencing for optimal solution stacking (wellfield recirculation) and Solvent Extraction (SX) processing during ISCR.

Iron and aluminum concentrations are often controlled by jarosite-alunite solid solution series. Jarosite-alunite saturation also commonly results in lower potassium concentrations than would be expected given potassium's high abundance in the host rock and relatively high solubility under acidic conditions. In general, the jarosite solid solution series is a very complex chemistry and can incorporate other major constituents such as sodium, hydronium, and even ammonium in the A sites. In addition, it can host trace elements such as lead (Piumbojarosite) in octahedral sites. However, thermodynamic data and models of these very complex solid solution series are not available. Some limited data for jarosite-alunite end members are available but are not incorporated into standard geochemical models and have to be integrated by custom databases. In very low pH solutions (<1), jurbanite may limit the solubility of aluminum.

Several minerals precipitated during the simulations including:

- Barite
- Gypsum
- Chalcedony
- $\text{Th}(\text{SO}_4)_2(\text{c})$
- Uranophane
- Pyrolusite
- Nontronit-Mg
- Alunite
- Gibbsite

- Thorianite
- Fluorite
- CuCr_2O_4
- Tenorite
- Beidellit-Mg
- Bixbyite
- Clinoptil-K
- Beidellit-Na
- Nontronit-Na
- $\text{CuFeO}_2(\text{c})$
- $\text{Ba}_3(\text{AsO}_4)_2(\text{c})$
- Saponite-Na
- CoCO_3
- Mirabilite

These minerals exert solubility controls on and attenuate concentrations of most of the primary constituents in the rinsed ore block after ISCR. Co-precipitation and sorption of constituents onto iron hydroxides and other precipitates may provide additional attenuation of constituents, but this reaction mechanism was not simulated in lieu of requisite site specific information.

The Forecast Composition of Commercial Grade PLS, shown in Table 3.1 as Solution No. [2] was derived from PLS composition data collected by BHP (1997 to 2004) during earlier pilot-scale ISCR testing in the vicinity of the PTF. Because of the short duration of the ISCR test phase, scaling laws were used to project measured copper grades to the target copper grades necessary for economic ISCR operation. The same scaling factor was used to estimate the attendant concentrations of gangue constituents in PLS during long term production scale operations. The estimate was derived by SWS by inspection of the PLS recovery curves in BHP injection wells BHP6, -7, 8, and 9 after inversion of those wells from injection to recovery in 1998. This occurred after the initial raffinate injection phase between November of 1997 and February of 1998. The PLS that was then recovered in these wells between May and July of 1998 is taken as the most "mature" leach solution as it had the longest residence time in the ore body during copper recovery. In that period, the maximum copper grade in solution (164.3 mg/L) was recorded in BHP-9 on 6/16/1998, and the nearly comprehensive chemical analyses that were conducted on samples of PLS collected from BHP 9 on that date were selected as a representative composition. This solution was also selected because it was within data validation criteria including charge balance, which is necessary for geochemical computer simulation (Alpers and Nordstrom, 1999). The target copper grade in solution is between 1.8 g/L to 2.0 g/L for the PLS to be economically processed using SX/EW, so copper and other constituents were multiplied by a factor of 11 to extrapolate the copper and attendant forecast concentrations of other constituents to estimate the production levels. This necessarily assumes that each constituent dissolves into solution at a linear rate during solution stacking.

Table 3.1 Estimated Composition of PTF ISCR Process Solutions

Solution No.	[1] Composition of 93 Percent H ₂ SO ₄ ¹ mg/L	[2] Forecast Composition of PLS mg/Kg	[3] Forecast Composition of Raffinate mg/Kg	[4] Estimated Composition of Pregnant Electrolyte (SX Strip Solution) mg/Kg	[5] Forecast Composition of Water Impoundment Solution with 20g/L Lime Treatment mg/Kg	[6] Forecast Composition of Water Impoundment Sediment After Evaporation mg/Kg	[7] Forecast Composition of Groundwater After Block Rinsing mg/Kg	[8] Make-up Water mg/L	AWQS ² mg/L
Metals									
Aluminum	0.012	602	631	110	628	3030	<0.001	<0.1	None
Antimony	0.012	0.0002	0.0002	0.1	0.0002	0.002	<0.001	<0.005	0.006
Arsenic	0.13	0.20	0.21	0.06	0.21	2.14	0.015	<0.002	0.05
Barium	<0.01	0.01	0.01	<0.2	0.01	<0.001	<0.001	0.08	2.0
Beryllium	NA	0.30	0.31	NA	0.31	3.22	<0.001	NA	0.004
Cadmium	0.039	0.008	0.008	25.0	0.008	0.086	<0.001	<0.005	0.005
Calcium	8.5	466	488	90	6473	64729	209	192	None
Chromium	0.045	0.14	0.15	15	0.15	1.5	0.009	<0.005	0.1
Cobalt	<0.01	68	7.1	15	7.09	73	0.003	<0.04	None
Copper	0.15	1806	175	51000	174	1792	1.87	<0.02	None
Iron	16	0.04	0.04	1650	0.04	0.12	<0.04	<0.04	None
Lead	0.19	0.11	0.12	<1	0.11	1.18	0.001	<0.002	0.05
Magnesium	NA	2795	2930	160	2915	29952	36.4	5.5	None
Manganese	0.045	40.2	42.1	0.014	41.9	431	1.15	<0.01	None
Mercury	0.013	0.48	0.50	<0.01	0.50	5.1	<0.001	<0.0002	0.002
Nickel	0.06	9.38	9.83	35	9.8	100.6	0.084	<0.04	0.1
Potassium	0.8	253	265	<0.01	264	2712	76.4	7.5	None
Selenium	<0.02	0.17	0.18	<0.1	0.18	1.82	0.001	<0.004	0.05
Sodium	11.0	2608	2731	110	2720	27957	245	200	None
Thallium	<0.01	0.003	0.003	<0.003	0.003	0.03	<0.001	<0.003	0.002
Zinc	0.27	6.98	7.31	245	7.3	75	0.062	<0.01	None
Anions									
Bicarbonate	<1	1.99	2.12	1	2.11	1.07	293	270	None
Chloride	<1	500	524	25	521	5360	378	320	None
Fluoride	NA	80.0	84	1	83	857	0.713	0.69	4.0
Nitrate	NA	96	92	NA	91	937	110	110	None
Phosphate	0.13	0.10	0.10	0.5	0.10	1.07	0.02	<0.2	None
Sulfate	1639592	35474	38974	214000	38790	266363	604	350	None
Field Parameters									
TDS	1639600	44747	46963	267483	52728	404387	1955	1500	None
pH	-1.22	3.02	1.40	0.01	6.5	6.5	6.40	7.30	None
Radiochemicals									
Ra 226 and 228	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.005
Uranium	NA	0.5	0.5	NA	0.52	5.36	0.0045	0.0078	None

Notes: ¹Recalculated pH from acid strength and summ of ions for TDS

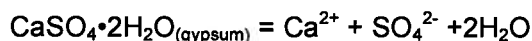
²AWQS = Arizona Water Quality Standard; Zallison and Allison, 2005, Lantz and Statham, 1994; logKd (L/Kg). None = no AWQS set in APP 101704

Errata:

NA = no data available for this constituent but estimated to be below detection limit

0.14 Estimated from Lantz and Statham, 1993 for COC's not measured in BHP field test

During continuous raffinate recycling sulfate and other gangue cations will build up in solution until they reach equilibrium with the raffinate-bleed stream flow rate or saturation with respect to a relatively insoluble sulfate salt or other solid phase that precipitates from solution. For example, in the case of calcium, gypsum solubility limits the grade of calcium in solution by the following reaction:



Calcium is readily leached from the host rock minerals, such as from calcite, feldspars and clay minerals, but the relatively low solubility product of gypsum ($\log K_{sp} = -4.58$ at STP) generally limits calcium solubility to 500 to 1000 mg/L depending upon the concentration of chloride and other species in solution. Precipitation of gypsum in the well field during ISCR operations effectively stores large amounts of sulfate in the formation, depending upon the original concentration and mineralogy of calcium in the host rock that will dissolve once fresh groundwater is reintroduced into the system. The sulfate released by dissolution of gypsum following cessation of ISCR operations will be removed by rinsing of the formation prior to closure of the well field.

The effect of gangue cation buildup is discussed in Paulson (1994). To simulate equilibrium controls the uncorrected PLS solution grade was reacted with 3% groundwater in the GWB program module "REACT" to simulate precipitation of saturated salts from solution. The new solution composition was used to replace the PLS component in Table 4.3-1 in BHP's original APP application. In addition, column leaching test results indicate that the projected leach solution composition was reasonable. It is projected that the leach solution will reach a steady-state composition during the PTF.

The projected concentrations were then entered into an input file for the program REACT, a module of GWB, to simulate the geochemical reactions that would occur when PLS is mixed with 3 percent make-up water as a result of over pumping at the perimeter production wells to maintain hydrologic control. Therefore, the resulting PLS composition (Table 3.1) includes the effects of chemical equilibrium reactions as well as mechanical mixing.

The Forecast Composition of Commercial Grade PLS [2] was used as the basis to estimate the composition of Raffinate [3], Water Impoundment Solution [5], Water Impoundment Sediment [6], and Groundwater Quality After Block Rinsing [7] using the program REACT to provide revised constituent concentrations shown in Table 3.1.

3.1.3 Raffinate solution composition

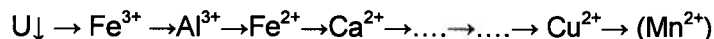
The Raffinate [3] composition was estimated by simulating the exchange of copper for acidity in the solvent extraction (SX) plant. The simulated extraction efficiency was similar to commercial SX operations (Spence and Soderstrom, 1999).

3.1.4 Water impoundment solution and sediment composition

The Forecast Composition of the Water Impoundment Solution [6] was estimated by simulated mixing of a Raffinate [3] bleed stream with a 20 g/L lime equivalent to neutralize the pH. As an outcome of this simulation, the Forecast Composition of the Water Impoundment Sediment [6] was estimated from the simulated precipitates that formed during the evapoconcentration of the treated raffinate influent to the impoundment. These precipitates consist predominantly of gypsum and other sulfate salts.

3.2 Groundwater composition – after block rinsing

The simulation of the Forecast Composition of Groundwater Quality after Block Rinsing [7] considers reaction of the leach solution with injected groundwater (assumed to be of the same composition as Make-up Water [7]) and the minerals in the depleted ore matrix such as residual chrysocolla and gangue minerals. The sequence of chemical precipitation of dissolved constituents during rinsing of the ore block after closure of the PTF ISCR operations is represented conceptually as:



As symbolized by its position and the downward arrow, uranium is attenuated most rapidly in the rinsed ore block. Uranium solubility decreases rapidly with increasing pH by precipitation of uranophane and the concentrations at the solubility limit are similar to background groundwater at the PTF. The remainder of the constituent concentrations are diminished as a result of sequential hydrolysis with increasing pH. Finally sulfate is removed to below the target concentration of 750 mg/L established in the closure requirements of the APP.

This simulation assumes complete displacement and removal of the residual leach solution in the pore spaces by injection and recovery of groundwater. As indicated previously, the assumed groundwater quality used for rinsing is defined by the concentrations of constituents in the Make-up Water component [8] shown in Table 3.1. The groundwater restoration simulation was run until the sulfate concentration was reduced to below the indicator concentration of 750 mg/L established in the closure requirements of the proposed temporary APP. As shown in Table 3.1, the results of the GWB simulation predict that none of the constituents will be present in groundwater at concentrations exceeding Aquifer Water Quality Standards (AWQS) once the resource blocks have been rinsed to a point where sulfate is below the target concentration of 750 mg/L. The model predicts that this concentration will be achieved after rinsing with a fresh water source that has a composition similar to the make-up water component [8].

Previous column and field testing by BHP and the current geochemical model simulations presented earlier in this section have demonstrated that the residual acidity of the PLS can be neutralized during well field restoration. For example, column testing conducted by BHP has shown that the LBFU and bedrock oxide zones have an acid consuming capacity of approximately 2 to 10 Kg/ton on a sulphuric acid mass basis. This acid neutralizing capacity should be sufficient to prevent migration or excursions of residual acidity from the ISCR operations.

An informal sensitivity analysis was conducted on the model by varying some of the model assumptions such as constituent release rates, and the overarching conclusions with regard to water quality compliance were not affected by variations of parameters within reasonable bounds.

4 CONCLUSIONS

The geochemical modeling simulation results generated by SWS (Table 3.1) show that successful post ISCR ore block restoration and process water treatment operations will achieve or exceed the performance criteria. Furthermore, these groundwater restoration simulations indicate that none of the constituents will be present in groundwater at concentrations exceeding AWQS.

5 REFERENCES

- Alpers, C.N., D.W. Blowes, D.K. Nordstrom, and J.L. Jambor. 1994. Secondary minerals and acid mine-water chemistry. pp. 247-270. In Jambor J.L., and Blowes, D.W., eds. Short Course Handbook on Environmental Geochemistry of Sulfide Mine-Wastes. Mineralogical Association of Canada, Waterloo, Ontario. May 1994.
- Alpers, C.N., and Nordstrom, D.K., 1999, Geochemical modeling of water-rock interactions in mining environments, in Plumlee, G.S., and Logsdon, M.J. (eds.), The Environmental Geochemistry of Mineral Deposits. Part A. Processes, Methods, and Health Issues, Society of Economic Geologists, Reviews in Economic Geology, v. 6A, chapter 14, p. 289-323.
- Bartlett, R.W., 1992. Solution Mining: Leaching and Fluid Recovery of Materials. Gordon and Breach Publishers.
- BHP Copper, 1997. Florence project final pre-feasibility report. Growth and Technology Group. December, 1997.
- Lantz, R.B. and Stathem, W. 1994. Modeling fluid movement at the Santa Cruz project. In Swan, S.A. and Coyne, K.R. eds.) 1994 In Situ Recovery of Mineral II. Engineering Foundation. Pp. 539-589.
- Larson, W.C., J.K. Ahlness, and S.E. Paulson. 1988. The Bureau of Mines' role in the development of true in situ copper mining as a future technology. Mineral Resources Engineering, February, 1988. 1(2): 171-180.
- Paulson, 1994. Effects of Fluid Recycling on Leach Solution composition: Implications for Copper In Situ Mining. In Swan, S.A. and Coyne, K.R. eds.) 1994 In Situ Recovery of Mineral II. Engineering Foundation. pp. 51-101.
- Schlumberger Water Services, 2010. Re Scope of work for the Florence in situ geochemical evaluation. Letter to ms. Loretta Ford Sustainability Manager. Curis Resoruces Ltd. From John Chabandour and James Oliver, Schlumberger Water Services, November, 2010.
- Seguin,, J.M., 1997. Overview of the BHP Florence (Poston Butte) Porphyry copper deposit, Pinal County, Arizona. Compiled by J.M. Seguin, March, 1997.
- Spence, J.R. and Soderstrom, M.D., 1999. Practical aspects of copper solvent extraction from acidic leach liquors. In Jergensen, G.V. (ed.) Copper Leaching, solvent Extraction, and Electrowinning Technology, SME Littleton, CO, p. 239 – 257.
- Tsang, C., 1991. Coupled hydromechanical-thermochemical processes in rock fractures. Reviews of Geophysics, 29, 4 November, p. 537-551.

SOURCES OF DATA:

BHP Florence Project Files and Database and APP Submittals (1997-1999)

Brown and Caldwell, 1996. Modeling Report. Magma Florence In Situ Project Aquifer Protection Permit Application, Volume IV of V. Prepared for Magma Copper Company, Florence Arizona. January, 1996.

Curis Resources (Arizona) Inc. Significant APP Amendment Application, Florence Copper Project SWS (2011). Geochemical Evaluation of Forecast Process solutions at the Florence Copper Project.

SOURCES OF MATHEMATICAL FORMULAE AND MODEL DOCUMENTATION:

Bethke, C.M., 2005a. The Geochemist's Workbench Release 6.0, Reaction Modeling Guide, a User's Guide to React and Gtplot. University of Illinois. June 4, 2005.

Bethke, C.M., 2005b. The Geochemist's Workbench Release 6.0, Reactive Transport Modeling Guide, a User's Guide to X1t, X2t, and Xtplot. University of Illinois. June 4, 2005.